BELLCOMM, INC.

SUBJECT: Review of the ATM Electrical Power System - Case 600-3

DATE: July 11, 1967

FROM: J. D. Dunlop
R. K. McFarland

ABSTRACT

The ATM Solar Array-Battery electrical power system preliminary design, and the criteria establishing the design has been reviewed. A considerable handicap has been placed on the ATM EPS design by MSFC, to provide reuse capability subsequent to AAP-4. This factor, in addition to a sincere effort on the part of MSFC to meet the original ATM delivery dates, has resulted in an EPS design that is overweight. If the EPS was designed for just the AAP-3/AAP-4 mission, and sufficient time existed to redesign and procure new array substrates, the EPS weight could be reduced by approximately 2000 Lbs.

FACILITY FORM 602

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(NASA-CR-154903) REVIEW OF THE ATM ELECTRICAL POWER SYSTEM (Bellcomm, Inc.) 17 p

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MEMORANDUM FOR FILE

On June 12 representatives of MSFC discussed the ATM electrical power system with R. K. McFarland and J. D. Dunlop of Bellcomm. Attendies from MSFC were: Charles B. Graff, Dwight Baker, Allen Anderson, Jimmy L. Miller, and Robert M. Counter.

INTRODUCTION

The ATM Solar Cell Array and Charger/Battery/Regulator Module preliminary design was discussed in depth. A copy of the preliminary design report is available through the authors. Two other reports received are the "ATM Solar Array Radiation Study" by John R. Morgan and "Solar Array Preliminary Power Study for ATM Gravity-Gradient Mode" by Leighton E. Young.

The LM/ATM electrical power system is designed to operate for 12 to 18 months in a 260 NM circular orbit. If this system was designed for just the 56-day AAP-3/AAP-4 mission substantial savings in weight could be realized, and an active rather than a passive battery temperature control system could be used. Thermal control of the batteries with the passive system is a major problem area in the current preliminary design.

It is the authors' opinion that the charger/battery/regulator module proposed is well designed for the design constraints imposed. However, the substrate for the solar cell modules is over weight by at least 600 lbs;if adequate time was available to redesign and procure new substrates a significant weight reduction could be realized.

MODULE DESIGN

The LM/ATM electrical power system consists of a 9.2 kilowatt solar cell array, twenty-four 270 watts charger/battery/regulator modules and required interfaces and circuitry. A block diagram of the modular power conditioning system is shown in Figure 1.[1] The charger/battery/regulator module along with load regulator and battery charger characteristics are shown in Figure 2.[1] The major design considerations are: (1) The modules will not be interdependent; (2) a module failure will not result in a system failure; (3) the modules shall have overload protection; and, (4) the load shall be shared equally by all modules.

BATTERY ASSEMBLY

The nickel-cadmium batteries are mounted in cast magnesium housings along with a battery charger and regulator to make up the module, a weight breakdown is as follows:

16.89	- housing
52.80	- cells, NiCd batteries
2.20	- potting compound 20 mils thick
14.00	- electronics
2.00	- potting for electronics
1.50	- connectors
89.39 Lbs	- Total weight per module

Total system weight:

24 modules at 89.39 ea.	= 2145
Battery mounts	= 361
Controls and wiring	= 582
Total System Weight	3088 Lbs

The battery system is overweight due primarily to efforts to insure a high probability of operation for a 12 to 18 month period. Additional battery modules have been added to the system to provide redundancy in the event of module failures. The 24 modules operate at a battery depth of discharge of 19%; if the system consisted of eighteen modules, the depth of discharge would be 25%. The number of batteries needed increases as the depth of discharge decreases. MSFC used 24 modules at the start of the mission assuming that 6 modules might fail over the 18 month period leaving 18 operating modules at the end of life.

Life tests on NiCd batteries indicate a depth of discharge of 60% for 1000 cycles is reasonable. There would be ∿1000 cycles during the AAP-3/AAP-4 56-day Mission. Therefore, the number of batteries could possibly be reduced by a factor of three (from 24 to 8 modules). For each module the weight associated with batteries is:

16.89	housing
52.8	batteries
2.2	potting compound
71.89 Lbs	Total weight associated with batteries per module.

Reducing the number of batteries by a factor of three reduces the weight by:

- Present weight allocated to batteries
  24 modules x 71.89 = 1725 Lbs
- Reduction in weight for 56-day operation using 8 modules
  2/3 x 1725 = 1284 Lbs

The weight penality for the 12 to 18 month design constraint is 1284 pounds just for NiCd batteries.

A second and possibly even more severe problem associated with the 12 to 18 month design constraint is the conclusion by MSFC that they must go to a passive temperature control system for the batteries. At 30°C, for each ampere hour drawn from the batteries, 1.38 ampere hours must be used in charging the batteries, as shown in Figure 3.(1) All of the overcharge is dissipated as heat. Current thermal analysis studies at MSFC show that for the 138% overcharge the passive system cannot reject the heat and maintain the batteries at 30°C. Therefore, MSFC is proposing to use a third electrode charge control scheme to reduce the amount of overcharge and thus the heat dissipated. Currently they are experiencing difficulty with the uniformity of the sensing voltage from the third electrode. For the AAP-3/AAP-4 56-day an active thermal control system could be used to eliminate this problem.

ATM SOLAR CELL MODULE WEIGHT

A weight summary of the solar cell module is presented in Table I. The substrate weighs 1.185#/ft^2 which is heavy compared to the Mariner 4 Mars system. For Mariner 4, the structure used to support the cells was ∿0.3#/ft^2 which is about 1/4 the ATM substrate weight.

Substantial weight savings of the present ATM substrate design would be possible if lighter materials were available. For example, the honeycomb core material currently proposed is 8.1#/ft^3. MSFC has on order 4.4#/ft^3 material and could use core material as low as 2 lb/ft^3, but because of military priorities, does not expect to obtain it. The same situation exists for the face sheet material. MSFC is using 20 mil face sheets where 5 to 10 mils could be used but is not available in the sizes needed.

Substrate			Substrate		
8.1#/ft^3 core	≃ 1.06		4.4#/ft^3 core	≃ 0.58	
20 mil face sheets	≃ 2.00		10 mil face sheets	≃ 1.00	
4 mil bonding	≃ 1.0		Bonding	≃ 0.9	
	4.06	Lb per module		2.48	Lb per module

With the lighter weight materials the substrate would weigh about 2.48 pounds per module (.725 lbs/ft^2), which would be approximately only twice as heavy at the Mariner 4 type substrate.

The substrate weight of 0.748 pounds per ft^2 would represents a weight saving of about 40%, per module. The total weight savings for the ATM array would be:

400 mod x 4.06#/mod =	1624
400 mod x 2.48#/mod =	992
Savings on substrate= weight	632 Lbs

The total weight for the ATM solar array using the module weights from Table I plus accessary weights is:

Solar cell modules 5.473 x 400 =	2189.2
Deployment and actuators	500.0
Actuating mechanisms	100.0
Scissoring mechanism	900.0
	3689.3 Lbs

The array performance at 70°C is then:

23.0 watts/module x 400 modules 9200 watts

9200 watts/3689.3# = 2.48 watts/pound.

The Mariner 4 measured array performance at 55°C was approximately 10 watts/Lb.

PERFORMANCE OF SOLAR ARRAY

The solar cell electrical characteristics specified in the MSFC-RFP are that the solar cell modules shall be 10% efficient based on the 3.8 cm^2 active area at 30 $\pm$ 2^oC. The solar cells must have an output of at least 120 milliamperes at 0.43 volts under a space solar simulator (140 $\pm$ 2 milliwatts per cm^2). The solar cell mounting arrangement is six cells operated in parallel by 114 in series, as shown in Figure 4.[1] Performance @ 30^{o}C:

114 x .43v = 49 volts/module

6 x .120 amperes = 0.72 amperes/module

49v x .72 amperes= 35.3 watts/module

This would be the performance with no degradation. The degradation effects are:

2% - Attenuation due to coverslides and Silgard 182 bonding adhesive.

3% - Effect of series parallel matching of solar cells.

6% - Radiation degradation after 12 to 18 months in earth orbit. This is the effect of uv degradation of the coverslides and high energy photon degradation (solar flare activity) of the solar cell.

2.0% - Blocking diode voltage drop (0.8v)

2.5% - line loss (1.0v loss).

19.5%- Temperature effect in going from 30^{o}C to 70^{o}C. The temperature coefficient is a degradation of 0.485% per degree centigrade rise in temperature from 30^{o}C.

35.00% - Total degradation

35% x 35.2 watts = 12.3 watts

35.3 - 12.3 = 23 watts/module

The 23 watts/module @ 70°C is the power per module design value currently being used by MSFC.

The performance of the solar array varies significantly with temperature as shown in Figure 5.(1) As stated above, MSFC is using 0.485% per degree centigrade in their study. This could be improved slightly with a maximum power tracking regulator scheme instead of the voltage clamping system. However, the overall effect would not be significant (0.4%/°C instead of 0.485%/°C). There is some question about the temperature of the array. There are several thermal studies being performed at MSFC, giving conflicting data. It is currently believed that the array average temperature may be more like 60 to 65°C instead of 70°C. A 10°C reduction in average temperature would improve the performance by about 5%.

Again the 12 to 18 month life requirement dictates the possible need for 12 to 20 mil coverslides and imposes a weight and performance penality upon the system. Currently MSFC is proposing 20 mil coverslides to reduce radiation loss after 18 months; using 6 mil coverslides a weight savings of 176# could be obtained.

Coverslide Thickness	Weight
20 mil	252 lbs
12 mil	151.6 lbs
6 mil	85.8 lbs

SUMMARY OF THE PENALTIES PAID FOR THE ATM 12 to 18 MONTHS REQUIREMENT AS OPPOSED TO DESIGNING THE SYSTEM FOR THE 56-DAY MISSION B.

1. Battery weight could be reduced by an estimated 1284 pounds.

2. An active thermal control system could be considered for the battery pack, eliminating a now difficult design problem-the passive thermal control system.

3. Six mil coverslides could be used for the 56-day mission resulting in a weight savings of 176 pounds in lieu of the 20 mil coverslides.

4. At the start of the mission, the solar array performance is better by 6% since there would be negligible radiation degradation. Thus the solar cell could provide either 6% more power or the weight of the EPS could be reduced by 6%.

5. Total possible weight savings:

Batteries	- 1284
Coverslides	- 176
Radiation 6%	- 132
	1592 pounds total

6. Substrate weight is not a function of the ATM mission duration; however, in summary, if the substrate was redesigned to obtain at least the .725 Lb/ft^2, an additional 632 Lbs could be saved for a total LM/ATM EPS weight reduction of 2224 Lbs.

J. D. Dunlop

R. K. McFarland

1022-JDD/RKM-mef

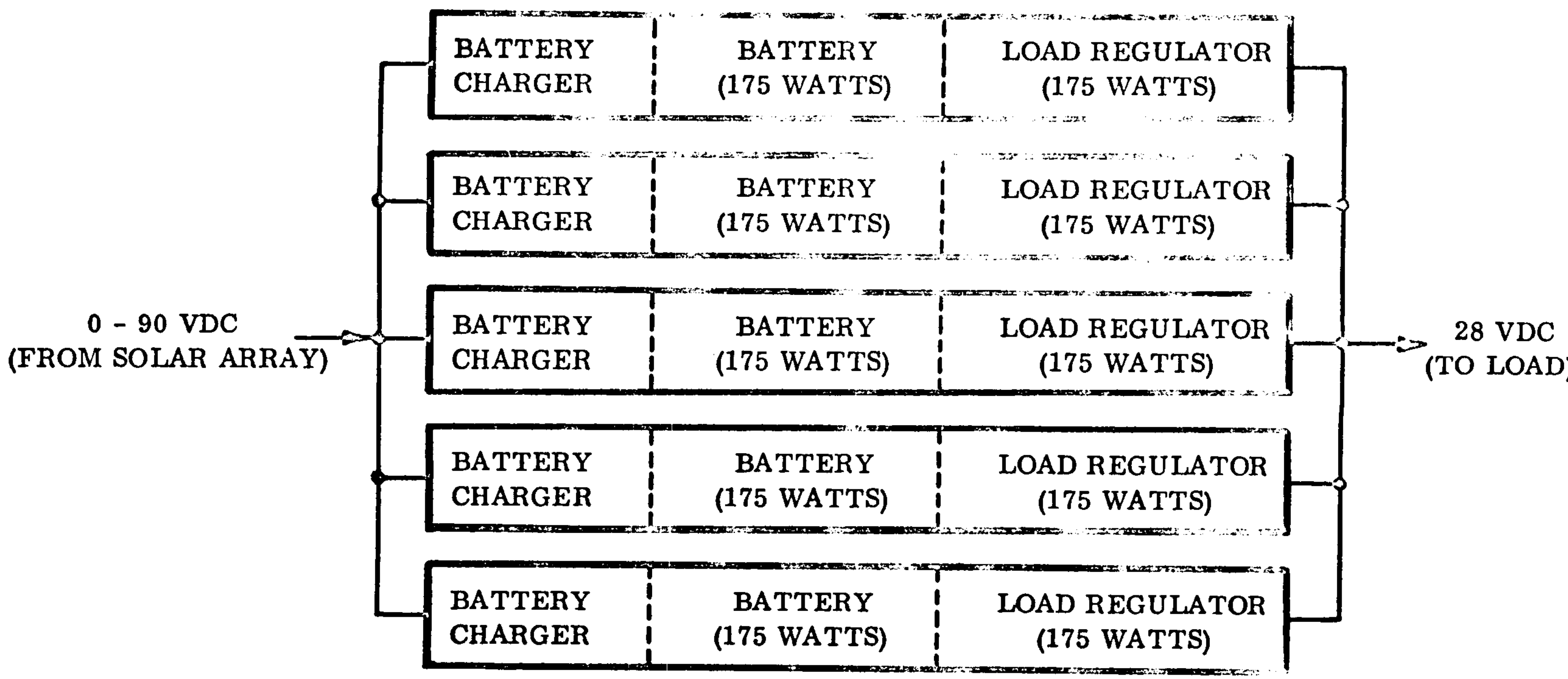
Attachments
Table I
Figures 1-5
References

ATM SOLAR CELL MODULE WEIGHT SUMMARY

	GRAMS	POUNDS	POUNDS/ft^2
Coverslide 0.012" Dow 7940	172.0	0.379	0.1105
Adhesive Sylgard 182	24.6	0.054	0.0157
Solar Cell 0.014" Solder Dipped	294.0	0.648	0.189
Adhesive RTV-577	49.2	0.108	.0314
Insulation 0.003" Micaply	14.4	0.031	.00905
Adhesive Slyastic 140	40.3	0.088	.0256
Substrate 0.020" Faces 2024-T3 and 8.1 #/ft^3 core	1841.0	4.062	1.185
Thermal Coating	9.0	0.019	.00555
Terminals	3.0	0.007	.00204
Hookup Wire	17.0	0.026	.00758
Contact Strips	23.2	0.051	.01485
TOTAL	2,487.7	5.473	1.60

Table I

MODULAR POWER CONDITIONING SYSTEM



FEATURES:

1. TOTAL LOAD REGULATOR CAPACITY = 875 WATTS
   (DELIVER 700 WATTS WITH SINGLE POINT FAILURE)
2. HIGH RELIABILITY
3. LOW WEIGHT
4. MINIMUM FILTERING
5. DESIGN STANDARIZATION
6. FLEXIBLE SYSTEM DESIGN

Figure 1

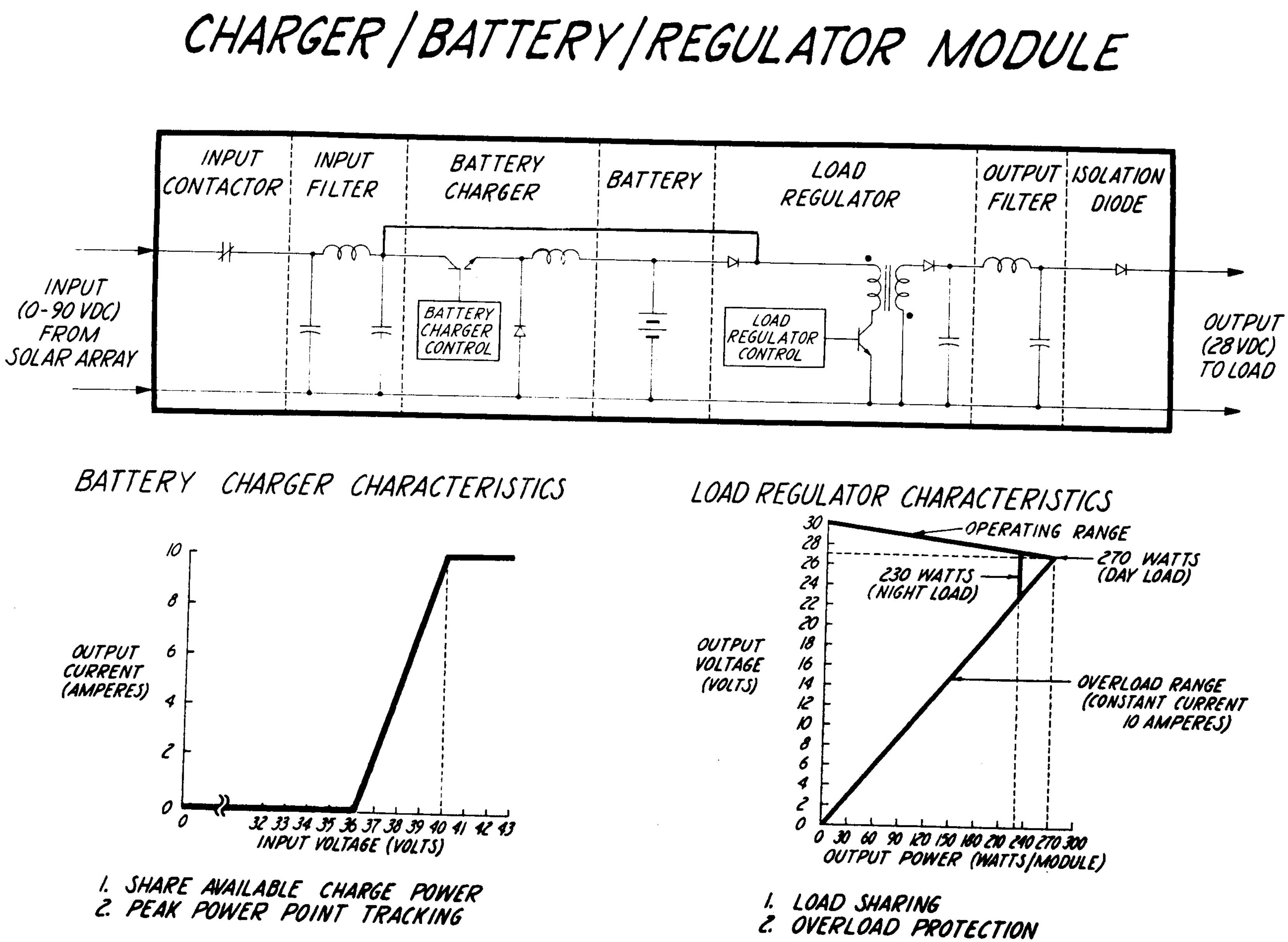

CHARGER / BATTERY / REGULATOR MODULE
INPUT CONTACTOR
INPUT FILTER
BATTERY CHARGER
BATTERY
LOAD REGULATOR
OUTPUT FILTER
ISOLATION DIODE
BATTERY CHARGER CONTROL
LOAD REGULATOR CONTROL
INPUT (0-90 VDC) FROM SOLAR ARRAY
OUTPUT (28 VDC) TO LOAD
BATTERY CHARGER CHARACTERISTICS
OUTPUT CURRENT (AMPERES)
10
8
6
4
2
0
0 32 33 34 35 36 37 38 39 40 41 42 43
INPUT VOLTAGE (VOLTS)
1. SHARE AVAILABLE CHARGE POWER
2. PEAK POWER POINT TRACKING
LOAD REGULATOR CHARACTERISTICS
OPERATING RANGE
270 WATTS (DAY LOAD)
230 WATTS (NIGHT LOAD)
OUTPUT VOLTAGE (VOLTS)
30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
OVERLOAD RANGE (CONSTANT CURRENT 10 AMPERES)
0 30 60 90 120 150 180 210 240 270 300
OUTPUT POWER (WATTS/MODULE)
1. LOAD SHARING
2. OVERLOAD PROTECTION

Figure 2

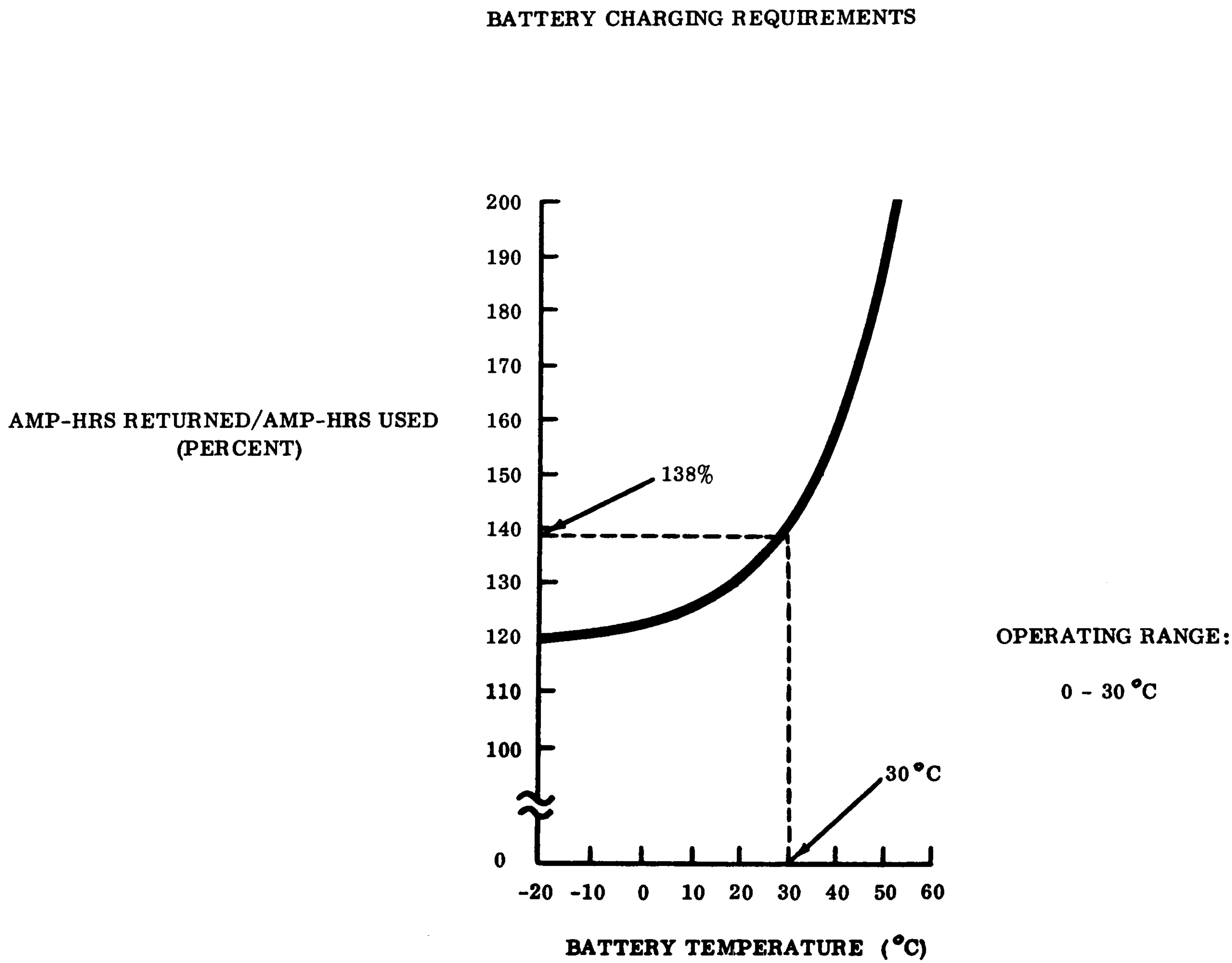
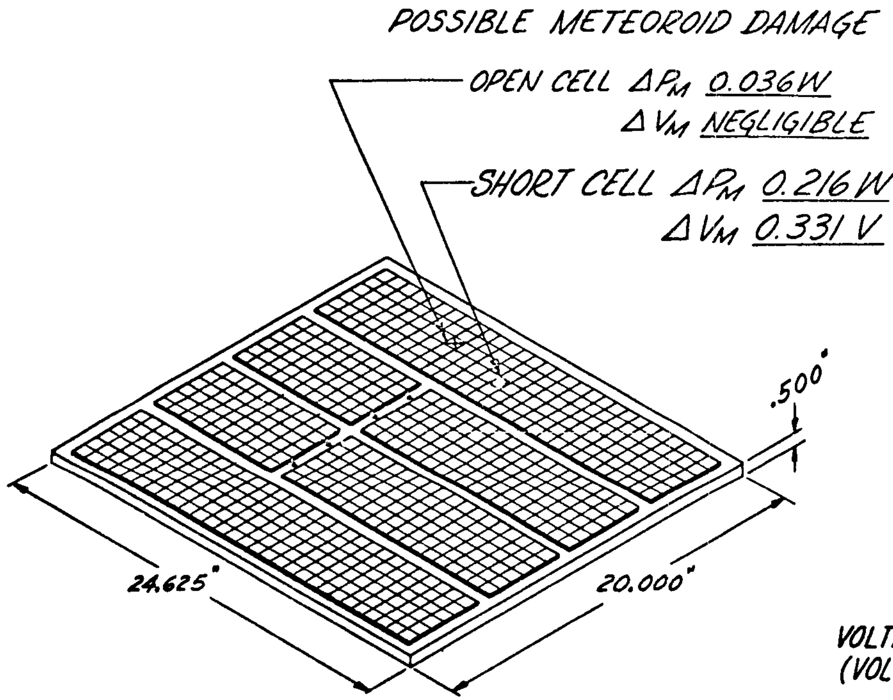

BATTERY CHARGING REQUIREMENTS
AMP-HRS RETURNED/AMP-HRS USED (PERCENT)
200
190
180
170
160
150
140
130
120
110
100
0
138%
30°C
-20 -10 0 10 20 30 40 50 60
BATTERY TEMPERATURE (°C)
OPERATING RANGE:
0 - 30 °C

Figure 3

SOLAR CELL MODULE



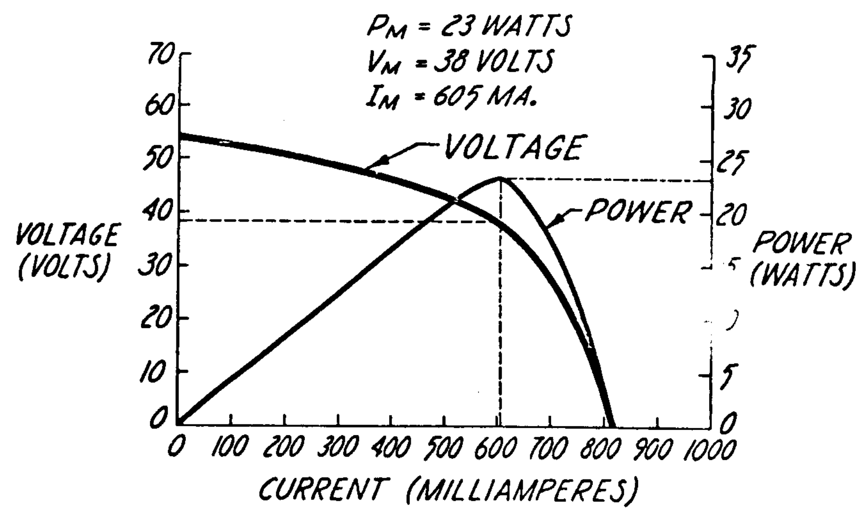
CONFIGURATION:

SOLAR CELLS
- 6 PARALLEL, 114 SERIES
- 2 CM × 2 CM
- N/P, 10 OHM-CM, 10% EFFICIENCY

0.020" QUARTZ COVERSLIDES

RATING AT 70°C:

P_M = 23.0 WATTS
V_M = 38.0 VOLTS
V_{oc} = 54.0 VOLTS



CHARACTERISTIC PERFORMANCE (70°C)

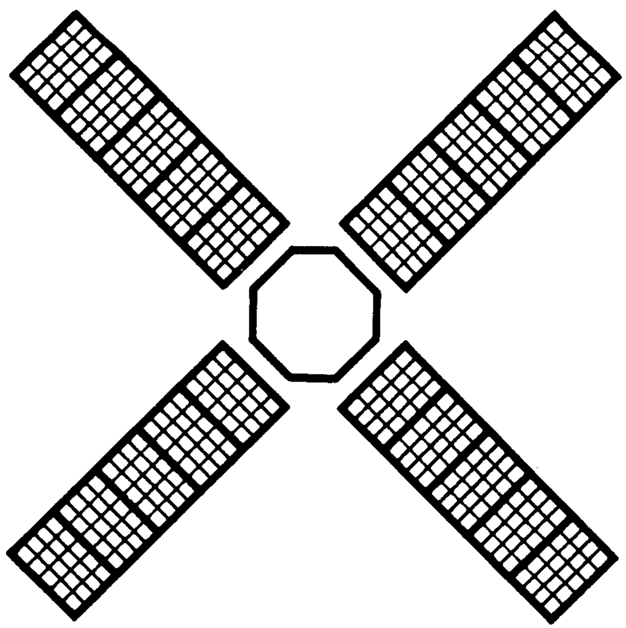
Figure 4

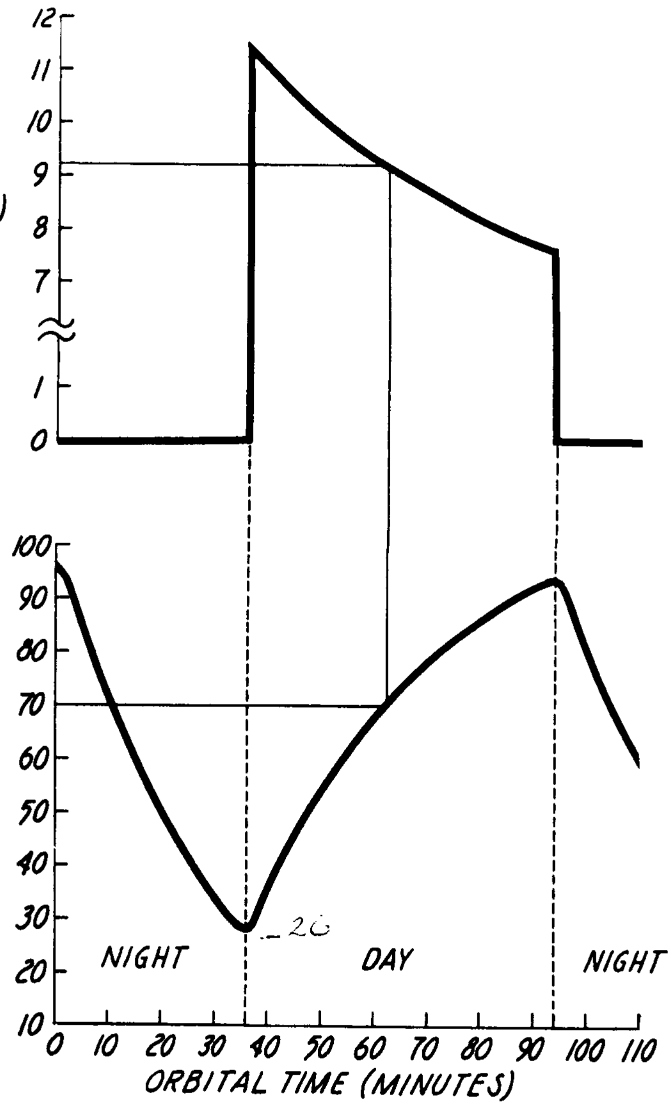
SOLAR CELL ARRAY

CONFIGURATION:
20 MODULES / PANEL
5 PANELS / WING
4 WINGS / ARRAY

WEIGHT:
157 POUNDS / PANEL
(WITHOUT DEPLOYMENT HARDWARE)

POWER RATING:
9200 WATTS AVERAGE
(2.93 WATTS / POUND AT 70°C)





POWER VS. TEMPERATURE NOMOGRAPH

Figure 5

REFERENCES

1. ATM Quarterly Technical Review, MSFC, March 8, 1967.

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